Fisheries Research 100 (2009) 240–247

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Can we increase haddock yield within the constraints of the Magnuson–Stevens Act?

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ARTICLE INFO

Article history:
Received 31 March 2009
Received in revised form 17 August 2009
Accepted 18 August 2009

Keywords:
Multi-species
Georges Bank
Haddock
Groundfish
Technological interactions
Ruhle trawl
Separator trawl
Fisheries policy options
Stakeholder views

ABSTRACT

Georges Bank haddock is a recently recovered fish stock in the New England groundfish fishery. Due to federal constraints under the Magnuson–Steven Act, however, this stock cannot be optimally exploited due to the bycatch of other critical species in the New England groundfishery such as cod and yellowtail flounder which are overfished. The Ruhle trawl and Separator trawl are examples of recent advances in gear technology that have been shown to significantly increase haddock to bycatch ratios. This study models the groundfish fishery through a mixed-stock yield model which incorporates technological interactions. We also develop a socio-economic model that quantifies the amount of employment and producer surplus associated with three trawl types. Our results explore policy situations regarding the use of the new trawls. By bridging the biological and socio-economic models, we are able to view the fishery as a system that more accurately represents stakeholder views. Our model shows that each trawl, when used exclusively, produces different optimum strategies and therefore an optimum management strategy would most likely include a combination of trawl types. Our results also support the logic of using modified trawls for haddock fishing trips in which bycatch is strictly regulated ("B days") as the Ruhle trawl is able to maintain 80% of catches caught by a conventional trawl while reducing bycatch up to over 60%. This paper is a first step towards an aid for policy makers to examine fishery gear trade-offs and the resulting biological and socio-economic consequences of different management actions within the constraints of the Magnuson–Stevens Act.

1. Introduction

Georges Bank, east of Cape Cod (Fig. 1), is an important historical fishing ground and was once among the most productive in the world (Boreman et al., 1997). However, many of the stocks greatly declined due to overfishing which set the stage for the reauthorization of the Magnuson–Stevens Fishery Conservation and Management Act in 1996. This legislation prioritized fisheries conservation in federal law; it prohibits overfishing and mandates rebuilding plans for all of the nation's stocks which are considered as overfished (Anonymous, 2006).

The Northeast Multi-species Fishery Management Plan, adopted in 1986, includes 19 different stocks. The fishery produces important technological interactions, meaning different species are caught with the same fishing gear (Murawski, 1984). The principal groundfish populations off New England are cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and yellowtail flounder (*Limanda ferruginea*). Fishermen have traditionally targeted the demersal stocks using relatively unselective gear. Today, the fishing gear used on Georges Bank is mainly bottom trawl (otter trawl) which represents about 80% of the gear used in the fleet.[1] Longliners and gillnetters make up the remaining percentage. The otter trawl, although equipped with a regulated minimum mesh size, is known for catching a mix of species, because it is dragged on the sea floor, and anything in its way can be caught in the net. As a result, fisheries that use otter trawls have large amounts of bycatch in their tows, forming the basis of Murawski's (1984) empirical foundation of the technological multi-species interactions in the groundfishery.

While yellowtail flounder and cod in the New England groundfishery are assessed to be both 'overfished' (i.e., low stock size)

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[1] Based on data from the National Marine Fisheries Service "dealer weighout database" (landings information provided by federally permitted seafood dealers).

0165-7836/$ – see front matter
doi:10.1016/j.fishres.2009.08.003

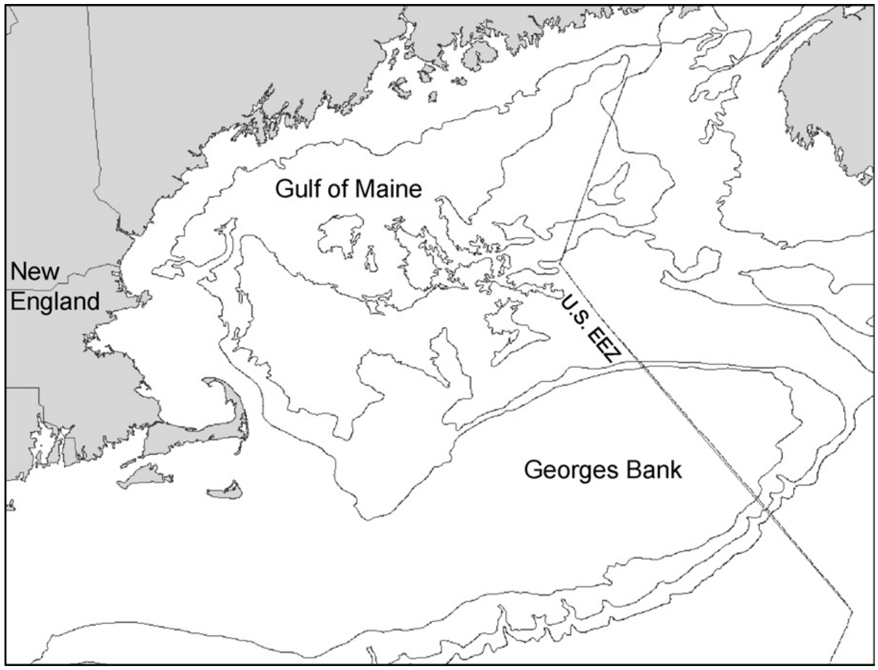

Fig. 1. A map of Georges Bank located east of the Northeastern coast of the United States.

with 'overfishing' still occurring (i.e., excessive fishing mortality), Georges Bank haddock is now considered a rebuilt stock (NEFSC, 2008). Non-selective fishing gears increase the amount of bycatch in the fishery and can hamper conservation and management efforts. Under the Magnuson–Stevens Act, fishermen may not fully target haddock with gear that also catches large amounts of overfished species such as cod and yellowtail flounder. Fishing with the otter trawl off New England led to the paradox of managing by the weakest link, forgoing potentials for employment and profit.

New technological advances in design of bottom trawls have led to two innovations to target haddock while minimizing bycatch of other species (Fig. 2). Since haddock tend to swim up when approached by fishing gear, in contrast to other species in the groundfishery, new modified trawls have succeeded to capitalize on this difference. The Ruhle trawl, formally known as the Eliminator trawl, incorporates a larger mouth design with 8 foot mesh size and a kite used to elevate the trawl in the water column for less bottom contact, thereby avoiding the overexploited cod and flounder

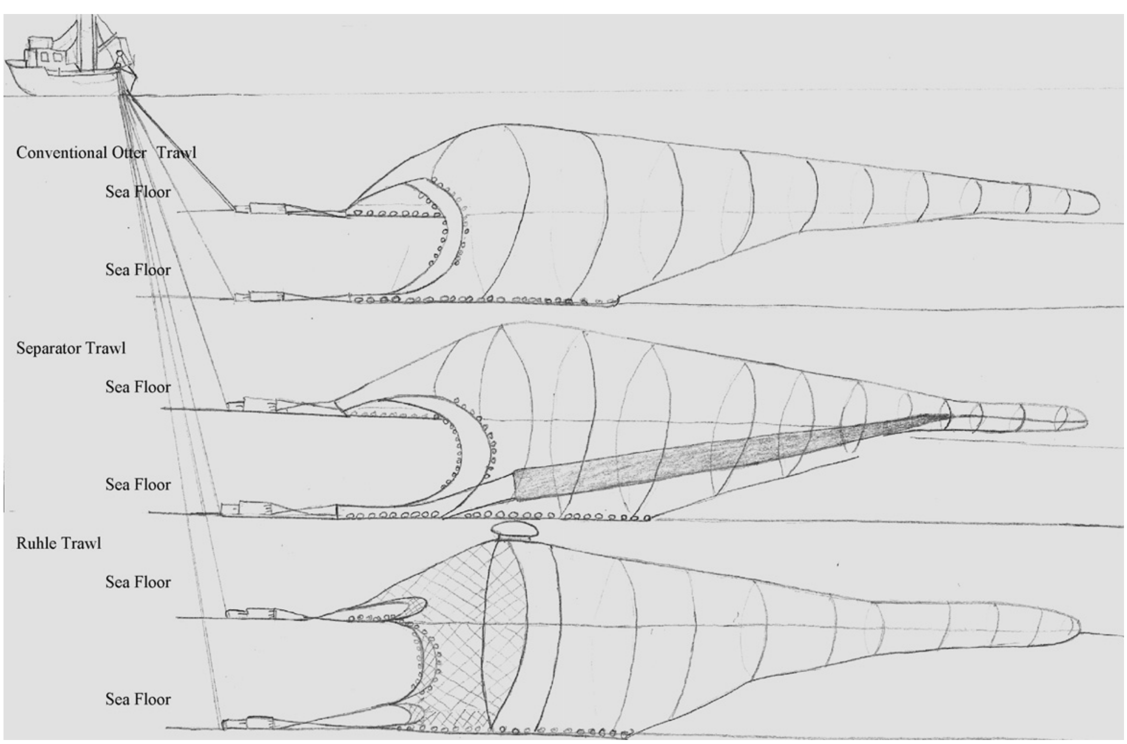

Fig. 2. An illustration of the main characteristics of the three trawls described in this paper. For more detailed information on the Separator and Ruhle trawls, refer to Martins et al. (2006) and Beutel et al. (2006, 2008). Drawing by Rachel DeLeon.

species and fragile bottom habitat (Beutel et al., 2006). The Separator trawl uses a standard otter trawl with a panel that horizontally separates the trawl into an upper and lower level, whereby the codend is attached to the upper panel while the lower panel is open allowing for bycatch species to safely pass through (Martins et al., 2006). Both the Separator trawl and the Ruhle trawl have shown, under experimental conditions, to have higher haddock to bycatch ratios. Experimental testing of the Ruhle and Separator trawls suggest significantly lower bycatch when haddock is the target species compared to the conventional otter trawl (Beutel et al., 2006, 2008; Martins et al., 2006). Although only a small portion of the Georges Bank fleet are currently using the modified trawl nets, a substantial portion of U.S. groundfish catch is allocated to an area in which only the modified trawls can be used.

Based on these studies, we hypothesize that better management alternatives arise with these new trawl gears than compared to the status quo management used in New England. In this paper, we link a mixed-stock population model with a socio-economic extension to project different outcomes from use of the three types of trawl gear.

Bridging biological and socio-economic effects of the conventional, Ruhle and Separator trawl types is an important aspect when managers are ready to consider them as fishery management options. Since fisheries management has inherent biological, social and economic components relating directly to the ecosystem (Charles, 2001; Utne, 2006), the scientific advice presented to managers and stakeholders should include all of these components in order to evaluate the entire issue (Sissenwine and Symes, 2007; Utne, 2006).

It is important that fisheries managers and stakeholders are able to analyze future policy decisions through the use of scientifically tested quantitative models. It is also of utmost importance that the model output is transparent and easily understood. Therefore, the purpose of this study is to analyze the short- and long-term (equilibrium) effects and trade-offs of these new gear types to four main utilities of the Georges Bank groundfishery: (1) yield, (2) employment, (3) producer surplus (revenue minus fixed costs) and (4) biomass of bycatch species, not including haddock.

2. Methods

Based on Murawski's (1984) mixed-stock yield per recruit model, Jacobson and Cadrin (2008) developed a mixed-stock yield model incorporating technological interactions of the groundfishery in New England. The model uses 2004 data from NOAA as input. The stocks included in the model are: Georges Bank cod, Georges Bank haddock, Georges Bank yellowtail flounder, American plaice (*Hippoglossoides platessoides*), witch flounder (*Glyptocephalus cynoglossus*), Gulf of Maine cod (*G. morhua*), and Cape Cod/Gulf of Maine yellowtail flounder (*L. ferruginea*).

Population dynamics are modeled as age-based processes with either average observed recruitment or stock–recruit relationships, consistent with current stock assessment practices (NEFSC, 2008). Fishing mortality for each stock (i) is derived as a function of mixed-stock fishing effort each year (E_t) and stock-specific catchability (q_i: the effect of a unit of effort on stock i):

$$F_{i,t} = E_t q_i \tag{1}$$

We conduct two simulations using two different models: a non-equilibrium 10-year projection starting with data from 2004, and then an equilibrium model projection where the amount of fishing effort, measured in days at sea (DAS), is varied. For each of these projections, we simulate the use of three different trawl types: (1) conventional groundfish trawl, (2) the Separator trawl, and (3) the Ruhle trawl.

2.1. Utility components

Following Hilborn (2007) we use four main outputs of the groundfishery mixed-species model as proxies for the main utilities of the fishery for its stakeholders: (1) yield, (2) employment, (3) producer surplus (i.e., revenue minus variable costs) and (4) the spawning stock biomass (SSB) of the species, which represents ecosystem preservation.

First, we calculate yield for the sum of all mixed species,

$$Y_{\text{ms},\,i,t} = \sum_i Y_{i,t} \tag{2}$$

where Y_{ms} is yield for the mixed species at time, t and i is the subscript for each species. We derive Y_i after Jacobson and Cadrin (2008) for equilibrium projections using Jacobson and Cadrin's method based on a yield per recruit analysis. For short-term projections, yield is a function of projected abundance (Jacobson and Cadrin, 2008).

We determine employment, E, based on a Holling Type II function with a limit at highest recent fishing effort for the New England groundfishery,

$$E_t = \frac{d\text{DAS}}{h + \text{DAS}} \times 365 \tag{3}$$

where h is maximum vessel days in a year (estimated to be larger than the average total allowed DAS for New England groundfishery over the last 10 years), d is a parameter describing the number of person hours in a vessel day, and DAS is fishing effort measured in DAS vessel days per year. Eq. (2) is then multiplied by 365 to get the units of E_t in employment hours per year.

Fishermen and policy-makers are often concerned about the profitability of the fishery. We calculate the producer surplus P_t, which is a proxy for profit, as,

$$P_t = \sum p_i Y_{i,t} - \beta \text{DAS}_t \tag{4}$$

where the price per species per kilogram is p and β is the trip cost.

Some stakeholders are concerned about the status of fish species in the ecosystem. We calculate the amount of the groundfish complex SSB as a proxy for this objective for the non-equilibrium projection in Eq. (4):

$$S_i = \sum_{a_{\text{mat}}}^{a_{\max}} (N_{i,a} m_{i,a} w_{i,a}) e^{-(F_i \cdot PR_{i,a} + M_i) ts_i} \tag{5}$$

where S_i is the SSB for each species (i), a_{mat} is the average age at maturity, $a_{\max}$ is the maximum age for each species, $N_{i,a}$ is the number of fish for each species and age, $m_{i,a}$ is the stock- and age-specific maturity index, $w_{i,a}$ is stock-specific weight at age, F_i and M_i are fishing and natural mortality, respectively, $PR_{i,a}$ is the partial recruitment of each species and age, ts_i is time of spawning for each stock which is a fraction of the year.

2.2. Input data

We use Jacobson and Cadrin's (2008) mixed-stock model that uses the Northeast Fisheries Science Center's recruitment estimates from 2004 to project the mixed-species yield forward in time (Jacobson and Cadrin, 2008). Jacobson and Cadrin (2008) estimated single species catchabilities (q_i in Eq. (1)) from fishing mortality from 2004 stock assessments and 2004 effort in DAS (DAS) from various sources. The Ruhle and Separator trawls were not approved yet in 2004, so 2004 conditions represent a control period against which we compare the new gear catchabilities.

The Ruhle trawl and Separator trawl have been each independently assessed in order to quantify their respective bycatch rates

Table 1
The catchability coefficients used to model the extent of technical interactions for seven species of groundfish in the Georges Bank area for three different fishing gear types.

Gear type (data origin)	Cod	Haddock	Yellowtail flounder	Cape Cod yellowtail flounder	Gulf of Maine cod	American plaice	Witch flounder
Conventional trawl (NOAA 2004)	6.7022E−06	6.7022E−06	3.3232E−05	2.0917E−05	1.7585E−05	4.1889E−06	5.5573E−06
Separator trawl (SMAST 2006)	4.1889E−06	7.3941E−06	2.4866E−05	1.5651E−05	1.7585E−05	4.1889E−06	5.5573E−06
Ruhle trawl (RISeaGrant 2006)	2.7926E−07	5.0267E−06	2.7926E−07	0.0	1.7585E−05	0.0	0.0

(Beutel et al., 2006; Martins et al., 2006). We derive the catchability coefficients for each of the seven stocks (Georges Bank cod, Georges Bank haddock, Georges Bank yellowtail flounder, Cape Cod yellowtail flounder, Gulf of Maine cod, plaice and witch flounder) for the Ruhle and Separator trawls by comparing the ratio of their control trawl (conventional otter trawl) catchability with their experimental catchabilities to our control catchability (NOAA 2004 data) from the respective reports of Beutel et al. (2006, 2008) and Martins et al. (2006).

The economic coefficients were derived using data from the NOAA observer program and economic analyses (Jin, 2008). We use 160,000 DAS per year as the maximum recently observed employment (Eq. (2)). We multiply this by 24 h to derive hours at sea per year. Our parameter d (Eq. (2)) is the number of person hours per vessel day which is 3.2 crew members per trip multiplied by 24 h.

2.3. Simulation set-up

We base the first simulation on the non-equilibrium model starting with 2004 values and projecting 10 years into the future, assuming a constant level of status quo fishing effort (of 35,809 DAS). For the second simulation we use the equilibrium model and vary the amount of fishing effort from 0 to 160,000 DAS, representing the maximum employment recently recorded (NOAA, 2000). For all simulations, we assume that each of the trawl gear types is used exclusively, so there is no combination of gears in the fishery. We also assume a haddock-targeted fishery with Georges Bank cod, Georges Bank yellowtail flounder, Cape Cod/Gulf of Maine yellowtail flounder, Gulf of Maine cod, American plaice, and witch flounder comprising the main six bycatch species (Table 1).

3. Results

We first review the results for each trawl gear from the model for the 10-year projections (Figs. 2 and 3, Table 2) when we hold employment constant at the level that occurred in 2004 (35,809 DAS). Then we review the results from the equilibrium projections (Figs. 5 and 6 and Table 3) for each gear type.

3.1. Non-equilibrium, deterministic 10-year projection

3.1.1. Conventional groundfish trawl performance

Fig. 2 illustrates haddock yield, overall producer surplus (including haddock and bycatch species) and haddock SSB results for the 10-year projection that focused on the biological response to the conventional otter trawl. Haddock yield peaks at year 5 as a result of a dominant 2003 year class (Panel a, Fig. 2 and Table 2). It then drops off to a steady state of approximately 60,000 t (Panel a, Fig. 2). Producer surplus of all seven stocks included in the model also peaks at year 5 at around $250 million followed by a 10% drop by year 10 (Panel b, Fig. 2). The SSB of haddock reaches its peak faster than haddock yield at year 3, thereafter a steep decline follows down to 500,000 t by year 10 (Panel c, Fig. 2 and Table 2).

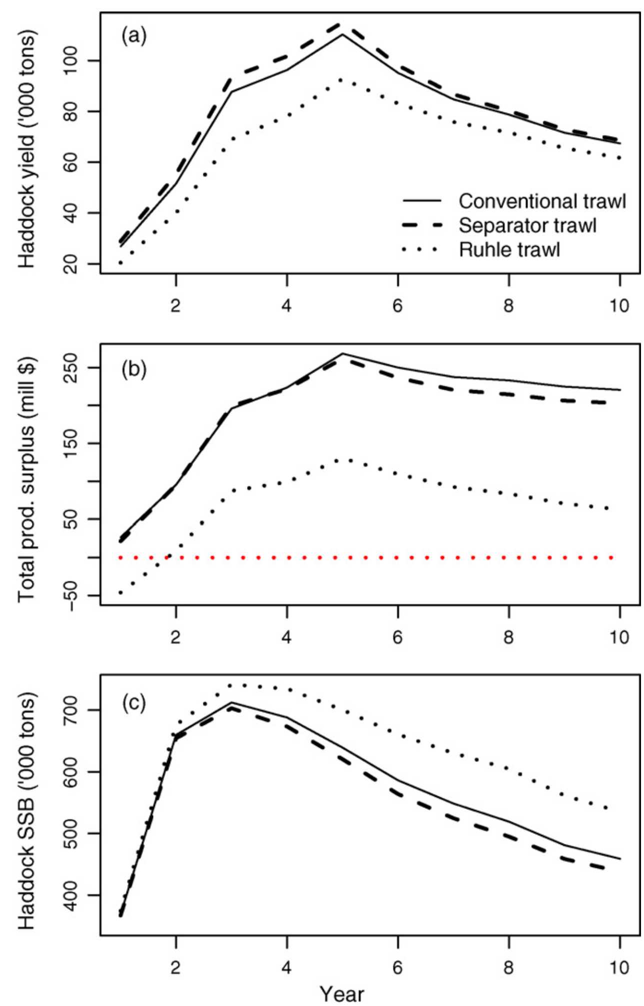

Fig. 3. Non-equilibrium, deterministic 10-year projection model results for the three utility components (haddock yield, all species producer surplus and haddock SSB) for the Georges Bank groundfishery using three modeled gear types (conventional otter trawl, Separator and Ruhle trawls). See Table 1 for the catchability coefficients used to represent each gear type in the model. Employment is fixed at 35,809 DAS from NOAA data from 2004.

Table 2
Results of the maximum levels of four performance outputs (columns) of three different gear types in the non-equilbrium simulation with constant employment (35,809 DAS).

Gear type	Haddock yield	All species producer surplus	Bycatch yield	Bycatch producer surplus
Conventional trawl	110,000 t	$250 million	71,000 t	$70 million
Separator trawl	115,000 t	$248 million	64,000 t	$55 million
Ruhle trawl	93,000 t	$101 million	19,000 t	−$50 million

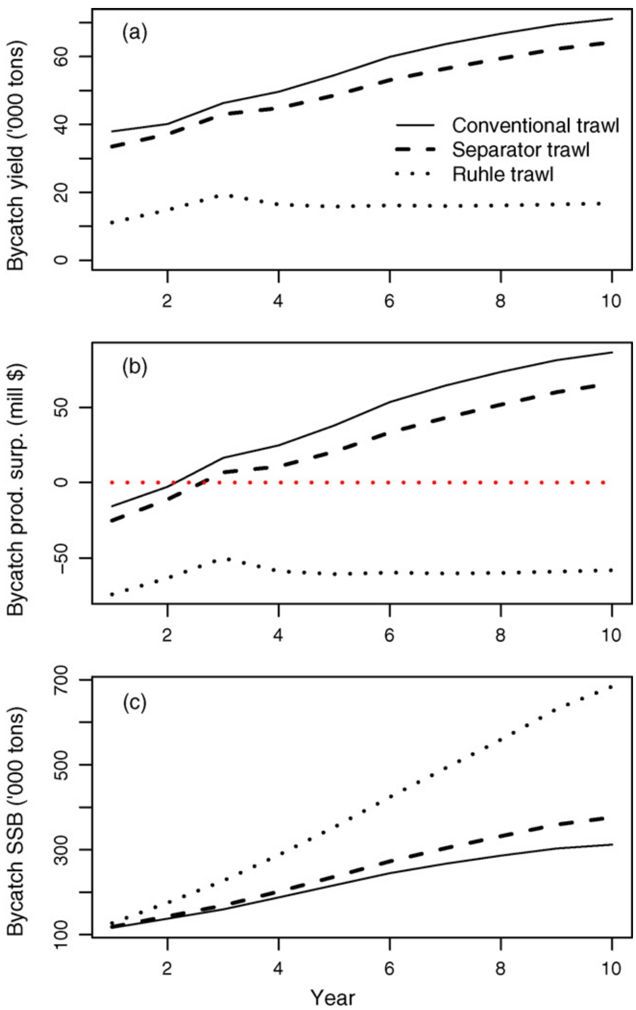

Fig. 4. Non-equilibrium, deterministic 10-year projection model results for the three utility components (bycatch yield, producer surplus based on bycatches and bycatch SSB) for the Georges Bank groundfishery using three modeled gear types (conventional otter trawl, Separator and Ruhle trawls). "Bycatch" refers to all modeled species except Georges Bank haddock. See Table 1 for the catchability coefficients used to represent each gear type in the model. Employment is fixed at 35,809 DAS from NOAA data from 2004.

Fig. 3 illustrates the yield, producer surplus and SSB results for the six bycatch species. When the fishery exclusively uses the conventional otter trawl, the yield of the bycatch species steadily increases to 70,000 t by year 10 (Panel a, Fig. 3 and Table 2). The SSB of the bycatch species increases through time to about 300,000 t by year 10 (Panel d, Fig. 3 and Table 2). The conventional trawl performs worst among the gear types considering bycatch species' SSB (Panel d, Fig. 3). In Figs. 2 and 3, the producer surplus curve follows the same trend as yield because effort is assumed constant so cost is constant.

3.1.2. *Separator trawl performance*

Use of the Separator trawl returns highest haddock yield of all gear types simulated as well as producer surplus which follows the same pattern (Panel a, Fig. 2 and Table 2). The trade-off is that the Separator trawl depletes the haddock SSB more than the other trawls (Panel d, Fig. 2). Yield of the mixed non-target species is lower than the conventional trawl after year 5 (Panel c, Fig. 3) and because of this, the resulting producer surplus is lower than that of the conventional trawl (Panel b, Fig. 3) and the resulting SSB of the non-target stocks increases faster in the 10-year simulation to almost 400,000 t (Panel d, Fig. 3).

3.1.3. *Ruhle trawl performance*

The Ruhle trawl is not as effective at catching haddock as the other two trawls (Panel a, Fig. 2 and Table 2), and as a result gives the highest haddock SSB of the other gear types of approximately 750,000 t in year 3 (Panel c, Fig. 2 and Table 2). We show the results of all seven groundfish stocks in Fig. 3. Here, use of the Ruhle trawl results in much less bycatch and a higher rate of stock rebuilding compared to the status quo otter trawl and to the Separator trawl. Most strikingly, the Ruhle trawl has a positive bycatch trade-off that gives higher multi-species SSBs with the maximum occurring at the end of the simulation in year 20 (Panel d, Fig. 2 and Table 2). The Ruhle trawl earns the least amount of producer surplus of all gears in both Figs. 2 and 3 (Panel b) due to the reduced income of the bycatch species (Panel b, Fig. 3).

3.2. *Equilibrium simulation*

3.2.1. *Conventional trawl performance*

We show long-term consequences of different management scenarios in Figs. 4 and 5 using the equilibrium results from the model at various fishing effort levels (DAS). Maximum haddock catch with the otter trawl occurs at a higher fishing effort than the Separator trawl (Panel a, Fig. 4 and Table 3), however maximum producer surplus for the conventional trawl requires fewer DAS than for the Separator trawl (Panel c, Fig. 4).

The bycatch yield increases quickly in likeness with haddock yield, but makes a sudden drop after 40,000 DAS due to depletion of the spawning stock (Panels a and d, Fig. 5).

Maximum producer surplus resulting from target and bycatch species combines follows the same pattern and then declines to negative producer surplus at about 50,000 DAS (Panel c, Fig. 4). For the bycatch species alone, maximum producer surplus peaks before maximum mixed non-target species yield (Panels a and c, Fig. 5 and Table 3). Producer surplus for these species goes to negative numbers after approximately 55,000 DAS (Panel c, Fig. 5).

3.2.2. *Separator trawl performance*

In the equilibrium simulation, the separator trawl achieves the highest haddock yield before the other two gear types at approximately 48,000 DAS (Panel a, Fig. 4). In Fig. 5, the maximum yield of all the bycatch species severely drops when DAS surpasses 50,000 (Panel a).

When we vary fishing effort, maximum haddock producer surplus occurs at a lower number of DAS than required for maximum haddock yield (Panels a and c, Fig. 4). The significant drop that occurs in yield after 48,000 DAS forces producer surplus to follow (Panel a, Fig. 4).

Table 3
Results of the maximum levels of four performance outputs (columns) of three different gear types in the equilibrium simulation. The associated employment levels for the maximums are given in parentheses.

Gear type	Haddock yield (employment)	All species prod. surplus (employment)	Bycatch yield (employment)	Bycatch prod. surplus (employment)
Conventional trawl	66,800 t (53,000)	$135 million (25,000)	61,600 t (48,000)	$105 million (20,000)
Separator trawl	66,800 t (49,000)	$120 million (35,000)	60,800 t (48,000)	$89 million (19,000)
Ruhle trawl	66,800 t (70,000)	$50 million (20,000)	19,800 t (150,000)	$16 million (17,000)

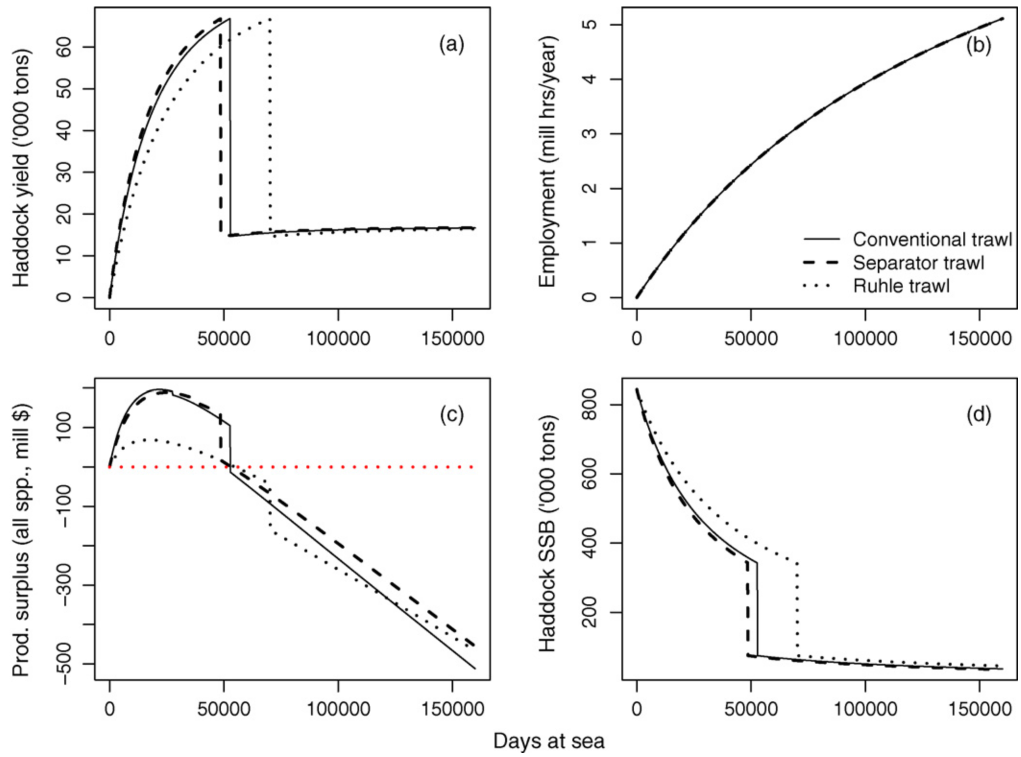

Fig. 5. Equilibrium model results for haddock for the four utility components (haddock yield, employment resulting from haddock-targeted fishing, producer surplus resulting from haddock-targeted fishing and haddock SSB) from a range of DAS from 0 (no fishing) to 160,000 (the approximate maximum observed from 2000) for three gear types (conventional otter trawl, Separator and Ruhle trawls). See Table 1 for the catchability coefficients used to represent each gear type in the model.

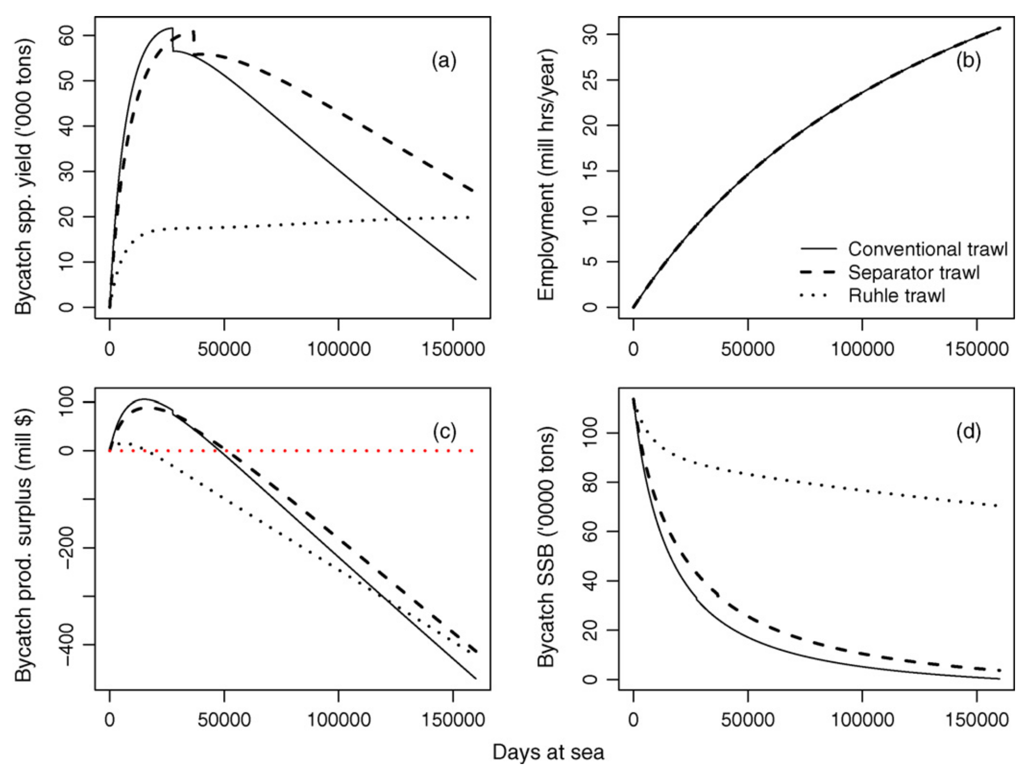

Fig. 6. Equilibrium model results for the six bycatch species (Georges Bank cod, Gulf of Maine cod, Cape Cod yellowtail flounder, Georges Bank yellowtail flounder, witch flounder and American plaice). Panels a–d show results for four utility components (bycatch yield, employment resulting from the bycatch, producer surplus resulting from the bycatch and mixed-species SSB resulting after the bycatch) from a range of DAS from 0 (no fishing) to 160,000 (the approximate maximum observed from 2000) and three different gear types (conventional otter trawl, Separator and Ruhle trawls). See Table 1 for the catchability coefficients used to represent each gear type in the model.

3.2.3. Ruhle trawl performance

Maximum haddock yield is equal to that of the other trawls (approximately 65,000 t) but at the expense of a higher fishing effort of about 70,000 DAS (Panel a, Fig. 4 and Table 3). Maximum yield of the bycatch non-target species is three times lower compared to the other trawl types (Panel a, Fig. 5) and therefore the bycatch SSB is not as negatively impacted by the Ruhle trawl as the other two trawls (Panel d, Fig. 5).

Haddock producer surplus obtained with the Ruhle trawl shows a much lower average yield that occurs at a higher amount of DAS than the other trawl types (Panel a, Fig. 4). Producer surplus for the assemblage of bycatch species peaks before the total yield of the bycatch species (Fig. 5 and Table 3). Overall, the Ruhle trawl shows the least producer surplus of the fishing gears due to low bycatch rates.

4. Discussion

Our results quantify the effect of different management scenarios for the New England groundfishery originating from three different trawl types and their effect on four utility components of the mixed fishery: yield, employment, producer surplus and the ecology (i.e. the SSB of seven different demersal species). The purpose of our quantitative results is not to give precise biological and economical advice, but rather to show trends on outcomes likely to happen with different trawl gears on the Georges Bank groundfishery as an aid to policy making.

For haddock, the Separator trawl is most effective in regards to yield and producer surplus when effort is limited between 10,000 and 49,000 DAS (Fig. 4). The Ruhle trawl is the only gear that can maintain profitability targeting haddock from 51,000 to 65,000 DAS (Panel a, Fig. 4). Common for all three trawls, there arises a maximum producer surplus at a lower amount of DAS than maximum yield at close to maximum employment levels. This indicates that, when used exclusively, these gear types have their own optimal level of fishing effort when producer surplus is the main objective. The conventional and Separator trawls give a much higher yield and producer surplus resulting from the bycatch species than the Ruhle trawl (Fig. 5). On the other hand, the Ruhle trawl allows for multi-species SSB stability at a level over twice as high as the conventional and Separator trawls for all levels of fishing effort (Panel d, Fig. 5).

Our model is able to quantify not only target species yield, but also yield of other species caught. For fishermen, it can be worth it to catch some non-target (bycatch) species because of the extra income and the fact that a boat can maximize its producer surplus at lower effort level due to a higher catch for the same cost per day. By using a combination of gear types, it seems possible for a fishing captain to maximize his producer surplus by targeting different species. Our results also support the logic of using modified trawls for haddock fishing trips in which bycatch is strictly regulated ("B days") as the Ruhle trawl is able to maintain 80% of catches caught by a conventional trawl while reducing bycatch up to over 60% (Figs. 3 and 4).

One unexpected result of our model is how pronounced the differences are between the Separator trawl and the Ruhle trawl in regards to haddock yield and projected biomass of the bycatch species (Figs. 4 and 5). A fleet using the Ruhle trawl exclusively has to fish 20,000 DAS more to catch the same amount of haddock as with the Separator trawl. The obvious trade-off here is how well the Ruhle trawl does at protecting important bycatch species, even at very high levels of fishing effort (Panel d, Fig. 5). This suggests that a combination of trawl types could be very useful in the fleet, which is what we see with some fishing operators on Georges Bank: our model suggests it is handy to have a Ruhle trawl available to be able to continue fishing even when the fleet's bycatch quota nears its end.

A similar bio-economic analysis of the Danish trawl fishery also indicated that there were trade-offs in the evaluation of more selective fishing gear (Kronbak et al., 2009). One of the methodological simplifications we made is that our model shows only technical multi-species interactions through catchability coefficients and ignores any ecological multi-species interactions that could occur through food web interplay or predator–prey interactions. This analysis does not take the impact of trawling on habitat into account. If it did, we expect that the Ruhle trawl would give less sea floor habitat disturbance as it employs a lighter footrope than other trawls for this specific reason, thereby increasing utilities for ecosystem preservation.

The model's short-term non-equilibrium projections are limited by the quality of the stock assessment data used as input; some specific uncertainties in stock assessments include decreases of the mean haddock catch weights between 7% and 44% in the period 2001–2004 (NEFSC, 2008) leading to likely overestimates of the stock. As a consequence, the short-term analyses may not be accurate, and relative trends are more reliable. We think that the long-term projections have valuable and more reliable strategic information. The long-term equilibrium projections (Figs. 4 and 5) shed light on relative levels of management action consequences of utility components (yield, employment, producer surplus and projected biomass of selected species) for the different gear types. This is consistent with the Magnuson–Stevens Act that emphasizes long-term sustainability of natural resources (Anonymous, 2006).

Fisheries economic theory suggests that profit in a fishery is maximized at a lower fishing effort than the effort associated with maximum yield. Figs. 1 and 2 have the same pattern in yield and producer surplus, because the cost is constant as a function of the constant effort assumed for the 20-year projection. The equilibrium simulation plot for the non-target species (Fig. 5 and Table 3) shows that producer surplus maximizes at less fishing effort than the effort for maximum yield for the trawls, which confirms standard economic theory and shows the usefulness of combining empirical economic data on producer surplus with biological models for management scenario exploration.

Our simplified estimation of the cost of fishing (Eq. (3)) assumes that costs are proportion to the amount of DAS incurred during a year. Vessel specific costs would be a good start of an extension to this simplification and could give insight towards sustainable management strategies in overcapitalized fisheries where fleet dynamics are highly influenced by vessel specific costs. Including variable costs would also help estimate actual profitability of the fishery; in this study, we estimate producer surplus as we have not included variable costs as a model simplification.

There is an increasing awareness among fisheries scientists and managers that stakeholder integration in the decision making process is very important to the success of fisheries management (Anonymous, 2007; Caddy and Seijo, 2005; Dankel et al., 2008; ICES, 2006; Rijsberman, 1999). Especially in the early stages of strategic planning, transparency and dialogue can enhance the probability that the resources stakeholders understand consequences of different management actions and therefore increase their buy-in in the final management decisions (Dankel et al., 2008; ICES, 2007; Jentoft and McCay, 1995; Paramor et al., 2005). Since fisheries have explicit biological as well as socio-economic effects, we illustrate our results through the quantification of yield, employment, producer surplus and multi-species biomass as we perceive these four utility components as a good summary of what the fishery's stakeholders are most interested in. Therefore, a practical implication of our results is increased stakeholder understanding as well as management scenario transparency that could occur in the important early phases of management or technical regulation development.

Our results are theoretical situations that show the biological (mixed-species biomass and yield) and socio-economic (employment and producer surplus) trade-offs that occur when fishermen use different gear types that target the mixed-species differently. Likewise, our modeled equilibrium results, in which we place more certainty than the deterministic non-equilibrium results, offer managers a quantitative aid to assess the effects diverse trawl types could have on both the ecological and socio-economic factors in a mixed-species fishery. This is especially important in the New England demersal fishery where potentially large haddock yields are restrained due to overfished stocks like yellowtail flounder and cod found in the bycatch. The results presented here do not go into specific constraints of the Magnuson–Stevens Act like stock-specific fishing mortality rates or rebuilding measures.

Our simplistic bio-socio-economic modeling framework described here is a start, not a destination, towards a more holistic understanding of trade-offs in fisheries management in Georges Bank. Details in the economics of shifting from one trawl gear to another, the likely mixture of gear types likely to be employed, complexities in effort constraints resulting in non-groundfish closures, as well as new allocations in sector management should gradually be implemented in our framework in order to adequately describe scientific and practical implications of fisheries management for the Georges Bank groundfishery.

We believe the framework put in practice in this paper, the linking of biological and socio-economic models, is the future for scientific advice to managers. It is important to be a part of an interdisciplinary scientific culture in order to answer inherent interdisciplinary questions policy and decision makers ask. According to our results, the answer to the question we pose in the title is, yes, it seems possible to increase haddock yield within the bycatch constraints of the Magnus Stevens Act. By taking an interdisciplinary approach and combining relevant economic, employment and biological data sets into a more holistic model that is not usually used in fisheries science, answers to difficult questions decision makers ask become possible.

Acknowledgements

D. Dankel acknowledges the Norwegian Research Council for funding of her doctoral work as well as her research visit to SMAST in Fairhaven, Massachusetts, USA. The authors thank Liz Brooks, Paul Rago, Brian Rothschild, and Stuart Reeves for constructive comments in the initial phases of this project. We thank Laura Skrobe and David Martins for data regarding the Ruhle and Separator trawls, respectively, and Drew Kitts and Eric Thunberg for assistance with the employment and economic data and application. We thank two anonymous reviewers for their most helpful comments on an earlier version of this paper. Special thanks to Rachel DeLeon for her collaboration in Fig. 2.

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